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A Multidimensional Rasch Analysis of the Functional Independence Measure Based on the National Institute on Disability, Independent Living, and Rehabilitation Research Traumatic Brain Injury Model Systems National Database

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Abstract

A number of studies have evaluated the psychometric properties of the Functional Independence Measure (FIM™) using Rasch analysis, although none has done so using the National Institute on Disability, Independent Living, and Rehabilitation Research Traumatic Brain Injury Model Systems National Database, a longitudinal database that captures demographic and outcome information on persons with moderate to severe traumatic brain injury across the United States. In the current study, we examine the psychometric properties of the FIM as represented by persons within this database and demonstrate that the FIM comprises three subscales representing cognitive, self-care, and mobility domains. These subscales were analyzed simultaneously using a multivariate Rasch model in combination with a time dependent concurrent calibration scheme with the goal of creating a raw score-to-logit transformation that can be used to improve the accuracy of parametric statistical analyses. The bowel and bladder function items were removed because of misfit with the motor and cognitive items. Some motor items exhibited step disorder, which was addressed by collapsing Categories 1–3 for Toileting, Stairs, Locomotion, Tub/Shower Transfers; Categories 1 and 2 for Toilet and Bed Transfers; and Categories 2 and 3 for Grooming. The strong correlations ($r = 0.82$-0.96) among the three subscales suggest they should be modeled together. Coefficient alpha of 0.98 indicates high internal consistency. Keyform maps are provided to enhance clinical interpretation and application of study results.

Key words: measurement; Rasch analysis; rehabilitation outcome; traumatic brain injury

Introduction

The primary objective of this study was to investigate the FIM™ instrument (previously the Functional Independence Measure) as contained in the Traumatic Brain Injury Model Systems (TBIMS) National Data Base (NDB) by way of Rasch analysis. The TBIMS NDB is a national database of treatment outcomes for persons with TBI.[1] In comparison with classic test theory, Rasch analysis is psychometrically advantageous because it provides an understanding of person ability as well as item difficulty and arranges estimates of each on an equal interval linear continuum. These features allow investigation of the dimensionality of an instrument, are robust against missing data, and allow transformation of ordinal measures to interval-level scaling.[2–4]

Score transformation is valuable because equal-interval measures can be used in parametric statistical analyses, where by doing so, accuracy of study results are improved. Such transformations of the FIM instrument have been performed for specific patient groups including persons with stroke, spinal cord injury, and TBI, yet none has been developed based exclusively on the data contained within the TBIMS NDB, representing the specific characteristics of these individuals.[5–11] Consequently, the aim of this study is to generate

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an interval-level transformation of the FIM instrument for the purpose of reducing measurement error, thus enhancing the accuracy of statistical analysis for studies using the TBIMS NDB.

Rasch models have evolved as our understanding of the approach has grown. For instance, tools such as keyform maps have been developed to facilitate clinical interpretation of measurements, and methods have been developed to manage violation of the assumption of independence among repeated measures.[11,12] Another advancement is the development of the Multidimensional Rasch Model (MRM), a special case of the Multidimensional Random Coefficient Multinomial Logit Model, which, among other features, allows latent ability to be a function of dimension.[13]

The MRM does not have the same constraints as does the traditional Rasch model, which requires all items within a measurement instrument to represent a single, unidimensional construct. Instead, MRM allows for inclusion of subscales that, when considered independently, are unidimensional, but when combined are not. For instance, in previous studies that concluded the FIM instrument was multidimensional, the authors' strategy was to model subscales separately as independent dimensions.[6,14,15]

In many cases, however, subscales are not independent, but are instead correlated. How well one performs on one subscale is associated with how well one performs on another, where the MRM considers the correlation between subscales in generating model estimates. Consequently, the MRM provides rehabilitation researchers and clinicians with an attractive option when the goal is to approximate interval level transformations for measurement instruments consisting of a set unidimensional yet correlated subscales. The advantages of applying the MRM have been discussed extensively.[13,16,17]

Methods

Instrument

The FIM instrument is an 18-item measure of burden of care associated with physical and cognitive functioning. Clinicians rate items on a 7-point scale that ranges from total assistance (1) to complete independence (7). The FIM assesses problem solving, memory, expression, comprehension, social interaction, eating, grooming, bathing, dressing–upper body, dressing–lower body, toileting, bowel management, bladder management, transfers to bed, chair, or wheelchair, transfers to toilet, and transfers to shower/tub, locomotion, and stair climbing. FIM instrument data are collected by TBIMS clinicians at admission and discharge from rehabilitation, and certified data collectors record scores by telephone interview 1, 2, and 5 years post-discharge and every 5 years thereafter.

Analytic approach and analysis

The MRM described in this article was developed in two stages: unidimensional Rasch model development and MRM building. The initial sample included 8909 TBIMS participants but was reduced to 8136 after dropping participants with extreme scores, which are not estimable in the Rasch model. All analyses were performed using standard Rasch/IRT analysis software packages: Winsteps Version 3.80.1 and ConQuest Version 3.0.1.

The sample was randomly split into three independent equal-sized subsamples before analysis. The subsamples contained FIM item information for one person at one time point—admission, discharge, and 1 year follow-up, respectively, using the method described by Mallinson.[12] These three samples were recombined before calibration so that the transformed measure is applicable to both cross-sectional and longitudinal analysis.

The collection of information was limited to admission, discharge, and 1 year follow-up time points because: (1) it is within these time points that the majority of change occurs and (2) sample size was maximized.[18] Analysis of differential item functioning conducted before calibration demonstrated no sufficient differences (>0.5 logits) between clinician-rated (i.e., admission and discharge) and telephone-administered (i.e., 1-year follow-up) FIM items.

The analysis focused on establishing the dimensionality of the FIM and assessing the extent to which item responses were monotonic (rating scale categories increased as patient ability increased). The initial calibration included all 18 FIM items. The data were fit to the Rasch-Masters Partial Credit model, because the assumption of a common threshold structure (i.e., identical distances between response options for each item) made by the Rasch-Andrich Rating Scale model was not expected.

Monotonicity was evaluated by comparing the average person ability measure associated with each item response. Unidimensionality was evaluated by principal components analysis (PCA) of residual variance not accounted for by the unidimensional Rasch model.[2] In combination with PCA, unidimensionality was established by way of parallel analyses, which were conducted to determine whether the separate dimensions accounted for more variance than similar dimensions in random data that fit the Rasch model.[19]

Specifically, three data sets were simulated based on estimated model parameters from the initial Rasch calibration and were analyzed using the same approach as described above. Finally, using the original sample, fit of the item responses to the Rasch model was examined using item infit and outfit statistics where values less than 1.5 indicate items perform well relative to the expectations of the model. Joint maximum likelihood estimation was used to calculate logit estimates and their corresponding standard errors.

On confirmation of the multidimensional nature of the FIM, we proceeded to fit the MRM under the Rasch-Masters Partial Credit paradigm. We compared deviance statistics from the MRM to its unidimensional counterpart—i.e., a single model that ignores subscales. In addition, we examined item infit and outfit using the same criterion noted above and investigated step disorder within items using item probability curves—i.e., Rasch-Andrich thresholds. Finally, we examined the separation reliability, coefficient alpha, and correlations between subscales.

Results

Sample characteristics

Women comprised 26.9% of the study sample. White patients comprised 73.1% of the sample, Black (18.9%), Hispanic (8.4%), and Asian (2.4%). The mean (standard deviation) age at injury was 39.6 (18.6) years. The sample included 33.1% who were married, 19.7% who were separated, divorced, or widowed, and 47.2% who were never married. The mean length of rehabilitation stay was 27.3 days (25.3).

Monotonicity and dimensionality

Study results are discussed starting with the examination of monotonicity and dimensionality in the actual and simulated samples. Person ability increased monotonically with item responses for all items in each sample. The PCA of Rasch residuals showed the first two contrasts (i.e., secondary and tertiary dimensions to the primary Rasch dimension) explained 4.6 and 2.0 eigenvalue units worth of residual variance, respectively. The variance explained by the measures and first two contrasts in the actual and simulated data are presented in Table 1.

Dissimilarity between the PCA of residuals in the actual and simulated data and eigenvalues ≥2.0 in the actual data suggested two secondary dimensions. Notably, the items with positive loadings on the first contrast were conceptually related: problem solving,

Table 1. Results of Parallel Analysis

	Study data	*Simulated data set #1*	*Simulated data set #2*	*Simulated data set #3*
Raw variance explained by measures	60.3 (77.0%)	62.3 (77.6%)	62.9 (77.8%)	61.9 (77.5%)
1st contrast eigenvalue	4.6 (5.9%)	1.7 (2.2%)	1.7 (2.1%)	1.7 (2.1%)
2nd contrast eigenvalue	2.0 (2.6%)	1.1 (1.4%)	1.1 (1.4%)	1.1 (1.4%)

memory, expression, comprehension, and social interaction (i.e., FIM cognitive subscale). Separate calibration of the cognitive FIM items indicated no item misfit. Accordingly, these FIM cognitive subscale items were removed and the remaining 13 motor items calibrated.

As in the previous calibration, person ability increased monotonically with item responses for all items. The PCA of Rasch residuals suggested two salient dimensions in the 13 ''noncognitive'' items: a ''mobility'' dimension composed of locomotion, stair climbing, transfers to toilet, transfers to shower/tub, and transfers to bed items, and a ''self-care'' dimension composed of grooming, dressing–upper body, dressing–lower body, bathing, and toileting items.

Bowel management, bladder management, and feeding items demonstrated misfit (>1.5) when modeled with either the mobility or self-care subscales and thus were removed from subsequent analysis. Separate calibration and analysis of item residuals suggested mobility (eigenvalue of first contrast = 1.7) and self-care (eigenvalue of first contrast = 1.5) subscales were unidimensional (≥ 2.0), and no item in either calibration demonstrated misfit (>1.5). These results replicate the work of Chen and associates[20] in 2002 who demonstrated that the FIM comprised three dimensions, although this article is the first to demonstrate the FIM consists of three dimensions based on a TBI population.[20]

Identification of the three subscales prompted development of a MRM. The initial calibration of the MRM showed no evidence of item misfit; however, Grooming, Toileting, Stairs, Locomotion, Toilet Transfer, Bed Transfer, and Shower/Tub Transfer items exhibited step disorder. To resolve this problem, categories were collapsed as follows: Categories 1–3 were collapsed for Toileting, Stairs, Locomotion, Tub/Shower Transfers; Categories 1 and 2 were collapsed for Toilet and Bed Transfers; and Categories 2 and 3 were collapsed for Grooming. After collapsing the categories, the resulting MRM had satisfactory fit statistics without step disorder.

Item estimates, corresponding standard error, and fit statistics are presented in Table 2. Once step disorder was eliminated, deviance statistics were used to compare the MRM with its unidimensional complement; results ($p < 0.0001$) suggest that the MRM provides a better characterization of the data. In addition, the three subscales were strongly correlated (Table 3), suggesting that treating them as independent entities is not warranted.

Construct definition

Table 2 presents the item difficulties arranged in ascending order for each item within its respective dimension. All outfit and infit statistics fall below 1.5, which indicates items adhere well to the Rasch model, while small standard errors reflect the precision of the estimates. A separation reliability of 1.0 suggests items will likely hold their relative positions in a similar sample where a coefficient alpha of 0.98 indicates high internal consistency.

A raw score to interval level transformation for each dimension is presented in Table 4. Raw scores reflect the aforementioned collapsing of categories.

Some readers may find the logit scale unwieldy. Thus, to enhance interpretation, the logit scale has been transformed so that it ranges from 0 to 100. Transformations for each dimension are provided in the supplemental content (Supplementary Table 1; see online supplementary material at ftp.liebertpub.com).

Discussion

The main goal of this study was to provide a raw score to interval level transformation for the FIM instrument using a MRM, and a secondary goal was to introduce the MRM to the rehabilitation research community. In achieving these goals, we extended previous studies that reported two subscales for the FIM and provide evidence that the FIM instrument, when administered to persons with TBI using the data contained within the TBIMS NDB, can be described as consisting of three dimensions measuring cognition, mobility, and self-care.

This scoring approach has several advantages over a combined motor subscale; separate self-care and mobility subscales are useful to rehabilitation clinicians because they correspond to the practices of occupational and physical therapy, respectively. Within the self-care domain, Grooming is the easiest item while the Toileting item is the most difficult. Likewise, within the mobility domain, the Bed Transfer item is easiest while the Stairs item is the most difficult. In examining the item hierarchy of the cognitive domain, we found the verbal comprehension item is easiest and the memory item is most difficult, where the overall item hierarchy for the cognitive subscale mirrors those of earlier studies.

The raw score to Rasch transformation tables can be used in statistical analyses of TBI samples. Because the transformed

Table 2. Item Estimates and Fit Statistics

Item	*Estimate*	*SE*	*Outfit*	*Infit*
Cognition (Dimension 1)				
Comprehension	–0.795	0.011	1.05	1.09
Expression	–0.601	0.010	1.00	1.04
Social	–0.428	0.010	1.29	1.28
Problem solving	0.844	0.010	0.86	0.95
Memory	0.980	0.021	1.00	1.07
Self-Care (Dimension 2)				
Upper body dress	–0.798	0.013	0.89	1.08
Grooming	–0.675	0.013	1.08	1.27
Lower body dress	0.107	0.012	0.88	0.96
Bathing	0.320	0.026	0.97	1.14
Toileting	1.046	0.013	1.30	1.15
Mobility (Dimension 3)				
Bed ransfer	–1.301	0.014	0.83	0.91
Toilet transfer	–1.108	0.014	0.72	0.82
Locomotion	–0.039	0.017	1.34	1.41
Tub/shower transfer	0.644	0.030	0.83	1.09
Stairs	1.804	0.015	1.23	1.35

SE, standard error.

Table 3. Correlation between Dimensions

Dimension	*Cognitive (1)*	*Self-Care (2)*
Self-Care (2)	0.85	–
Mobility (3)	0.82	0.96

measures approximate interval level scaling, they are useful with parametric statistics that assume measures are equal-interval and distributed normally. The added precision of the transformed subscores provided by the MRM are an additional benefit. Although greater precision is warranted in conducting any statistical analysis, increased precision may be especially salient when applied to the investigation of change in function over time modeled at the individual level, as is done in random effects modeling such as individual growth curve analysis.

In conjunction with transformation tables, keyform maps provide a link between expected within item endorsement—i.e., categories within the items—and the total score (or the logit equivalent). A keyform map for each dimension can be found in the Supplementary Figures 1, 2, and 3; see online supplementary material at ftp.liebertpub.com).

Keyform maps indicate, based on a range of logit values, which item category is most likely. For example, the Mobility keyform map (Supplementary Fig. 2; see online supplementary material at ftp.liebertpub.com) suggests that for the Locomotion item (delineated by a triangle), a response of 1, 2, or 3 on the item falls between negative infinity to −3.06 logits, a response of 4 falls between −3.06 and −1.89 logits, a response of 5 falls between −1.89 to 0.87 logits. This configuration allows one to determine, for a given item rating, which categories, across items, are likely to be endorsed. For instance, based on the Mobility dimension keyform map, raw score of 20 (or a logit equivalent of −1.71) corresponds to a score of 4 (minimal assistance) on Bed, Toilet, and Tub/Shower Transfers, a 5 (supervision) on Locomotion, and a score of 1, 2, or 3 (total to moderate assistance) on the most difficult item, Stairs.

Keyform maps allow clinicians to examine a patient's functional status at the item level, as well as monitor progress and goal setting. Bode and colleagues[11] describe the many clinical-related benefits of keyform maps.[11]

Development of this MRM represents an evolutionary step in measurement science for rehabilitation. While MRM provided a more suitable model for the FIM instrument, it is not necessary for other instruments that are unidimensional or multidimensional instruments that have subscales that have little to no correlation with each other. Over time, MRM models can be developed and integrated into practice for the FIM instrument for other populations and for other multidimensional scales. For clinical and research samples that resemble TBMIS NDB participants, clinicians and researchers now have a MRM model to facilitate analysis and interpretation of rehabilitation outcomes that accounts for correlations between subscales.

Table 4. Raw Score to Logit Transformation for the Three Functional Independence Measure Dimensions

Raw score	*Logits (cognitive dimension)*	*SE (cognitive dimension)*	*Logits (self-care dimension)*	*SE (self-care dimension)*	*Logits (mobility dimension)*	*SE (mobility dimension)*
5	−5.99	1.58	-	-	-	-
6	−4.71	0.96	-	-	-	-
7	−4.02	0.78	-	-	-	-
8	−3.51	0.69	−6.44	1.6	-	-
9	−3.09	0.63	−5.05	0.99	-	-
10	−2.73	0.59	−4.31	0.80	-	-
11	−2.40	0.57	−3.78	0.70	-	-
12	−2.10	0.54	−3.36	0.64	-	-
13	−1.82	0.53	−2.99	0.60	−6.12	1.53
14	−1.56	0.51	−2.66	0.58	−4.94	0.96
15	−1.30	0.50	−2.34	0.57	−4.28	0.81
16	−1.05	0.50	−2.03	0.56	−3.74	0.75
17	−0.811	0.50	−1.73	0.56	−3.22	0.73
18	−0.572	0.49	−1.42	0.57	−2.70	0.71
19	−0.332	0.50	−1.10	0.57	−2.20	0.70
20	−0.088	0.50	−0.77	0.59	−1.71	0.68
21	0.16	0.50	−0.42	0.60	−1.26	0.65
22	0.411	0.51	−0.05	0.61	−0.86	0.63
23	0.670	0.51	0.34	0.63	−0.49	0.61
24	0.932	0.52	0.76	0.64	−0.14	0.60
25	1.21	0.53	1.19	0.64	0.21	0.60
26	1.49	0.54	1.61	0.63	0.57	0.62
27	1.78	0.55	2.00	0.62	0.95	0.63
28	2.09	0.57	2.37	0.61	1.36	0.66
29	2.42	0.59	2.72	0.61	1.81	0.68
30	2.78	0.62	3.07	0.62	2.30	0.72
31	3.17	0.66	3.44	0.64	2.83	0.76
32	3.63	0.72	3.85	0.69	3.43	0.82
33	4.18	0.82	4.34	0.77	4.16	0.93
34	4.96	1.01	5.00	0.94	5.14	1.13
35	6.38	1.66	6.24	1.55	6.80	1.80

SE, standard error.

Limitations

This study used data from the TBIMS NDB; thus, results are generalizable primarily to TBIMS study participants. Results of this study cannot be compared precisely with earlier publications because this study used a MRM along with a concurrent calibration scheme. Thus, item difficulty estimates are based on information gathered at admission, discharge, and 1-year follow-up.

Conclusions

Because of the correlation between subscales, this study more used a MRM instead of treating subscales as independent to increase measurement accuracy. In addition, for persons with TBI, we demonstrated the FIM instrument comprised three unidimensional subscales measuring cognitive, self-care, and mobility domains that correspond to the clinical foci of psychologists and speech-language pathologists, occupational therapists, and physical therapists, respectively. Within each subscale, the Rasch transformed scores can be used in parametric statistical analyses to increase the accuracy of results. Finally, to aid in interpretation of study results, keyform maps can be used to translate raw scores into likely category responses within items, which allows for estimation of functional status and can assist in patient progress monitoring as well as goal setting.

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References

1. Dijkers, M.P., Harrison-Felix, C., and Marwitz, J.H. (2010). The Traumatic Brain Injury Model Systems: history and contributions to clinical service and research. J. Head Trauma Rehabil. 25, 81–91.
2. Bond, T.G., and Fox, C.M. (2001). *Applying the Rasch model: Fundamental Measurement in the Human Sciences.* Erlbaum: Mahwah, N.J.
3. Andrich, D. (1988). *Rasch Models for Measurement.* Sage Publications: Newbury Park, CA.
4. Boone, W.J., Staver, J.R., and Yale, M.S. (2014). *Rasch Analysis in the Human Sciences.* Springer: Dordrecht, the Netherlands.
5. Heinemann, A.W., Linacre, J.M., Wright, B.D., Hamilton, B.B., and Granger, C. (1993). Relationships between impairment and physical disability as measured by the Functional Independence Measure. Arch. Phys. Med. Rehabil. 74, 566–573.
6. Heinemann, A.W., Linacre, J.M., Wright, B.D., Hamilton, B.B., and Granger, C.V. (1994). Measurement characteristics of the Functional Independence Measure. Top. Stroke Rehabil. 1, 1–15.
7. Linacre, J.M., Heinemann, A.W., Wright, B.D., Granger, C.V., and Hamilton, B.B. (1994). The structure and stability of the Functional Independence Measure. Arch. Phys. Med. Rehabil. 75, 127–132.
8. Brock, K.A., Goldie, P.A., and Greenwood, K.M. (2002). Evaluating the effectiveness of stroke rehabilitation: choosing a discriminative measure. Arch. Phys. Med. Rehabil. 83, 92–99.
9. Lawton, G., Lundgren-Nilsson, A., Biering-Sorensen, F., Tesio, L., Slade, A., Penta, M., Grimby, G., Ring, H., and Tennant, A. (2006). Cross-cultural validity of FIM in spinal cord injury. Spinal Cord 44, 746–752.
10. Lundgren-Nilsson, A., Tennant, A., Grimby, G., and Sunnerhagen, K.S. (2006). Cross-diagnostic validity in a generic instrument: an example from the Functional Independence Measure in Scandinavia. Health Qual. Life Outcomes 4, 55.
11. Bode, R.K., Heinemann, A.W., Kozlowski, A.J., and Pretz, C.R. (2014). Self-scoring templates for motor and cognitive subscales of the FIM instrument for persons with spinal cord injury. Arch. Phys. Med. Rehabil. 95, 676–679 e5.
12. Mallinson, T. (2011). Rasch analysis of repeated measures. Rasch Measurement Transactions 251, 1317.
13. Adams, R.J., Wilson, M., and Wang, W.-c. (1997). The multidimensional random coefficients multinomial logit model. Applied Psychological Measurement 21, 1–23.
14. Dickson, H.G., and Kohler, F. (1996). The multi-dimensionality of the FIM motor items precludes an interval scaling using Rasch analysis. Scand. J. Rehabil. Med. 28, 159–162.
15. Granger, C.V., Linn, R.T., Markello, S.J., and Fiedler, R.C. (2000). Case-mix in rehabilitation: FIM-based function-related groups. Clin. Rehabil. 14, 110–111.
16. Briggs, D.C., and Wilson, M. (2003). An introduction to multidimensional measurement using Rasch models. J. Appl. Meas. 4, 87–100.
17. Wang, W.C., Wilson, M., and Adams, R.J. (1998). Measuring individual differences in change with multidimensional Rasch models. J. Outcome Meas. 2, 240–265.
18. Pretz, C.R., Kozlowski, A.J., Dams-O'Connor, K., Kreider, S., Cuthbert, J.P., Corrigan, J.D., Heinemann, A.W., and Whiteneck, G. (2013). Descriptive modeling of longitudinal outcome measures in traumatic brain injury: a National Institute on Disability and Rehabilitation Research Traumatic Brain Injury Model Systems study. Arch. Phys. Med. Rehabil. 94, 579–588.
19. Raîche, G. (2005). Critical eigenvalue sizes in standardized residual principal components analysis. Rasch Measurement Transactions 19, 1012.
20. Chen, C.C., Heinemann, A.W., Granger, C.V., and Linn, R.T. (2002). Functional gains and therapy intensity during subacute rehabilitation: a study of 20 facilities. Arch. Phys. Med. Rehabil. 83, 1514–1523.

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